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Evaluation of the nutritive value of legume alternatives to soybean meal for broiler chickens

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ABSTRACT Five experiments were conducted to investigate the nutritional value of various legumes and a faba beans processing co-product for broilers. In Expt. 1 and 3, metabolizable energy (AME) content was evaluated for 2 batches of bean starch concentrate (BSC) that differed in physical and chemical characteristics. Standardized ileal amino acid digestibility (SIAAD) was determined for BSC in Expt. 2, and for corn, soybean meal (SBM), organic and conventional faba beans, and quinoa (Expt. 4). The growth performance response of broiler chickens to partial replacement of wheat and SBM with various legumes was investigated in Expt. 5. The AME of the BSC assayed in Expt. 1 was lower ($P < 0.01$) than that of the BSC assayed in Expt. 3. The SIAAD was generally high for BSC in Expt. 2 although the content and digestibility of sulfur amino acids were low. In Expt. 4, there was no difference in SIAAD of Arg, Phe, Asp, and Gly among the different feedstuffs assayed. SIAAD was largely similar for both conventional and organic faba bean. The SIAADs of Met, Thr, Ser, and Tyr were lower ($P < 0.05$) for quinoa compared with SBM or corn. In Expt. 5, FCR was greater ($P < 0.05$) for broiler chickens receiving faba beans+barley mix or lupins compared with the wheat-SBM control diet. Amino acid digestibility was greater ($P < 0.01$) for the diets containing lupins compared with the other diets except for Lys, Met, Thr, Ala, Asp, and Ser. On the other hand, amino acid digestibility in diet with faba beans+barley mix was lower ($P < 0.05$) compared with all the other diets, except for Arg, Asp, Lys, and Thr. It was concluded from the current studies that there is scope for using the assayed legumes, co-products, and quinoa in broiler chickens to partly replace SBM as protein feedstuffs.

Key words: faba bean and concentrate, quinoa, metabolizable energy, amino acid digestibility, broilers

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INTRODUCTION

Soybean meal (**SBM**) is the most commonly used plant protein feedstuff for non-ruminant animals. However, factors such as high cost, EU legislations, consumer perceptions regarding genetically modified feedstuffs, and environmental concern are driving the search for alternative protein feedstuffs for poultry and pig industries.

Alternative legumes that can, at least, partially reduce dependence on SBM include various non-oilseed legumes (pulses) that are widely cultivated in Europe, including the UK. For example, faba beans are widely cultivated in Europe and their nutritional value has been reported in various studies (Vilariño et al., 2009; Masey O'Neil et al., 2012; Abdulla et al., 2016b). Nevertheless, there is continued interest in understanding the nutritive value of the legume due to effects of different agronomic practices on its digestible nutrient content. Other feedstuffs of interest are lupins (Nalle et al., 2011; Kaczmarek et al., 2014; Jerock et al., 2016) and quinoa, for which there is comparatively less information in the literature (Gonzalez et al., 1989; Improta and Kellems, 2001).

Processing can improve nutritive value of pulses with value addition to their products and co-products. One such processing is air classification which was previously described (Vose et al., 1976) as a processing technique that separates fine-ground pulses to protein- and starch-rich fractions on the basis of differences in their weight and density. Air classification adds value to both fractions by increasing their protein contents (Gunawardena et al., 2010b). The protein-rich fraction of air-classified faba beans has been tested as a replacement for soy protein concentrate in salmon feed (De Santis et al., 2016), but there is a dearth of information on the nutritive value of the starch-rich fraction (bean starch concentrate [**BSC**]) for poultry.

Therefore, the objective of the experiments was to evaluate the nutritive value of faba beans grown under various agronomic practices (conventional, organic,

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Table 1. Analyzed chemical composition (g/kg) of the test feedstuffs.

	Expt. 1 and 2	Expt. 3	Expt. 4					Expt. 5		
	BSC1[1]	BSC2[1]	Corn	SBM	Organic faba bean	Conventional faba bean	Quinoa	Faba bean	Faba bean/barley mix[2]	Lupin
DM	888	888	880	891	897	868	887	915	912	909
GE, kcal/kg	3,800	3,991								
Starch	520	425								
N	26.9	37.4	11.8	74.1	40.4	42.7	28.9	39.7	36.5	50.2
Arg	16.7		3.6	33.1	20.7	22.8	13.6			
His	4.5		2.0	12.1	6.1	6.5	4.7			
Ile	8.0		2.4	21.2	9.2	9.7	5.7			
Leu	13.7		7.8	35.2	17.1	18.1	10.0			
Lys	11.3		2.3	27.9	14.7	15.8	8.7			
Met	1.2		1.5	6.5	1.7	1.9	3.7			
Phe	7.6		3.9	23.0	10.8	11.2	7.5			
Thr	5.8		2.9	17.6	10.9	9.2	6.3			
Val	8.5		3.0	21.0	11.5	11.9	6.9			
Ala	7.7		4.2	19.5	9.1	9.7	5.9			
Asp	20.2		5.2	52.6	25.5	27.2	13.2			
Cys	2.2		1.7	5.9	2.9	3.0	2.7			
Glu	30.5		12.7	83.1	39.1	41.1	23.5			
Gly	8.0		2.5	18.8	9.5	10.1	8.2			
Pro	6.2		5.2	23.9	8.8	8.7	5.1			
Ser	7.3		3.8	22.8	10.9	11.5	7.0			
Tyr	6.4		1.5	13.4	7.5	6.7	4.2			

[1]BSC—bean starch concentrate—obtained from air fractionation of ground, debranned faba beans. BSC1 was in pellet form, whereas BSC2 was in powder form (not pelleted).

[2]Faba beans + barley mix was primarily faba bean harvested in field of faba beans intercropped with barley, consequently with potential for dilution of faba beans with barley during harvesting.

or legume/cereal mixed cropping), lupins, quinoa, and BSC in diets for broiler chickens. The focus was on determining the AME and standardized amino acid digestibility (**SIAAD**) of the various feedstuffs, as well as the growth performance response of broilers receiving diets in which faba beans or lupins partly replaced SBM.

MATERIALS AND METHODS

All the animal experiments reported here were approved by Scotland's Rural College Animal Welfare and Ethical Review Body. Five experiments were conducted to determine the AME and SIAAD of BSC in broiler chickens (Expt. 1 and 2, respectively); AME of a second batch of BSC (Expt. 3); SIAAD of corn, SBM, organic faba bean, conventional faba bean, and quinoa (Expt. 4); and growth performance and apparent ileal amino acid (**AA**) digestibility responses of male broiler chickens to partial replacement of SBM with lupin or faba beans (Expt. 5).

Feedstuffs Tested

Bean Starch Concentrates The BSC samples were obtained from air classification of dehulled faba beans (*Vicia faba* L.). The protein-rich fractions obtained in the processing of the beans in the current study were used in salmon feeding experiments as reported by De Santis et al. (2015, 2016). The BSC used in Expt. 1 and 2 (BSC1) was in pellet form (without any additive used), whereas the BSC used in Expt. 3 was in coarse powder form (BSC2). The 2 BSC were different in starch, protein, and gross energy (**GE**) contents, which reflected variation in the extent of protein removal during the air classification process.

Legumes The organic and conventional faba beans (*Vicia faba* L.) used in Expt. 4 were obtained from experimental fields of Scotland's Rural College (**SRUC**) under organic or conventional agronomic conditions, respectively. The legumes were not processed in any way apart from drying and removal of impurities. The faba beans used in Expt. 5 were similarly obtained and processed as for Expt. 4. The faba bean + barley mix (Expt. 5) were obtained under intercropping agronomic condition with both faba beans and barley grown together in the same field. The lupin (*Lupinus angustifolius*) used in Expt. 4 was also derived from SRUC agronomic fields.

Other Feedstuffs The quinoa (*Chenopodium quinoa*), SBM, and corn were obtained by the feed mill from commercial suppliers and the latter 2 were used as reference feedstuffs in Expt. 4.

The chemical composition of all the feedstuffs tested is presented in Table 1.

Expt. 1

A total of 72 male Ross 308 broiler chickens were used for the experiment. The birds were raised together and received nutrient-adequate diets for the first 2 wk posthatch. On day 14, the chickens were weighed and allocated to 3 treatments in a randomized complete block design. The diets were a corn-SBM reference diet and 2 additional diets in which BSC1 proportionately replaced the energy yielding feedstuffs (corn, SBM, and

Table 2. Ingredients and chemical composition (g/kg) of experimental diets (Expt. 1, 2, 3, and 4).

	Expt. 1	Expt. 2		Expt. 3	Expt. 4				
Items	AME[1,2]	NFD	SIAAD	AME[1,2]	Corn	SBM	Organic faba bean	Conventional faba bean	Quinoa
Corn	696			554.5					
SBM	240			370					
Corn starch		210.8				129.5	39.7	39.7	
Dextrose		640				379.5	116.3	116.3	
Arborcel (cellulose)		50							
Soybean oil	26	35		26	25	25	25	25	25
Dicalcium phosphate	10.5			18					
Monocalcium phosphate		19	19		19	19	19	19	19
Limestone	15	16	16	17	16	16	16	16	16
NaCl	4		4	4	4	4	4	4	4
Titanium dioxide	5	5	5	5	5	5	5	5	5
Vit-Min premix[3]	3	5	5	3	5	5	5	5	5
DL-Met	2.5			2.5					
KCl		4							
MgOxide		0.7							
Choline chloride		2.5							
$NaHCO_3$		12							
Test feedstuff			951		926	417	770	770	926
Total	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Analyzed composition, g/kg									
Protein	164	12.5	142	226	65	194	191	193	128
ME, kcal/kg[4]	2,820	3,346	3,203	3,035	3,179	3,131	3,107	3,107	3,083
Ca[4]	8.5	9.1	9.3	10.7	9.4	10.5	11.8	9.9	10.0
P[4]	6.0	4.0	6.7	7.0	6.4	6.7	13.2	5.5	7.8
Non-phytate P[4]	3.4	4.0	4.8	4.6	4.5	4.9	5.4	5.5	4.0
Analyzed total amino acids, g/kg									
Arg		0.5	10.8	15	3.20	13.30	15.90	16.30	9.70
His		0.4	2.9	6	1.90	4.70	4.50	4.80	3.50
Ile		0.5	5.3	9.5	2.20	8.00	7.20	7.50	4.60
Leu		1.8	9.1	19.4	7.30	13.40	12.80	13.50	7.50
Lys		0.2	7.4	12.4	2.00	11.00	11.10	11.80	6.70
Met		0.3	0.9	6.0	1.40	2.30	1.30	1.50	2.50
Phe		0.6	4.9	10.8	2.90	8.70	7.30	7.90	4.70
Thr		0.4	3.8	8.5	2.30	6.80	6.10	6.80	4.20
Val		0.7	7.1	10.4	3.50	8.00	7.70	7.80	5.10
Cys		0.4	1.4	3.7	1.60	2.30	2.00	2.30	2.10
Tyr		0.4	4.2	8.9	1.20	4.90	4.40	4.70	1.90
TSAA		0.7	18.1	42.5	11.7	28.1	24.4	26.3	18.6

[1]BSC—bean starch concentrate—was obtained from air fractionation of ground, debranned faba beans. BSC1 was in pellet form, whereas BSC2 was in powder form (not pelleted).

[2]The diet formulas are for the reference diets. Two additional diets were formulated for each experiment in which 300 or 600 g/kg of BSC proportionately replaced all the energy-yielding feedstuffs of the reference diets. The ratio of the energy-yielding feedstuffs remained constant in all experimental diets.

[3]Vitamin A, 5,484 IU; vitamin D3, 2,643 ICU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg, d-panthothenic acid, 11 mg; niancin, 44.1 mg, choline chloride, 771 mg; vitamin B12, 13.2 μg; biotin, 55.2 μg; thiamine mononitrate, 2.2 mg; folic acid, 990 μg; pyridoxine hydrochloride, 3.3 mg; iodine, 1.11 mg; manganese, 66.06 mg; copper, 4.44 mg; iron, 44.1 mg; zinc, 44.1 mg; selenium, 300 μg.

[4]Calculated values.

soya oil) at the rate of 300 or 600 g/kg. Each treatment had 8 replicates and 3 birds per replicate. The diets were fed for 7 D, and excreta were collected on the last 3 D of the experiment (analyzed for DM, GE, titanium dioxide, and N). The ingredient and chemical composition of the diets are shown in Table 2.

Expt. 2

A total of 96 male Ross 308 broiler chickens were used for the experiment. The birds were raised together and received a nutrient-adequate diet for the first 24 D posthatch. On day 24, the chickens were weighed and allocated to 2 treatments in a randomized complete block design. The diets were a N-free purified diet (NFD) and a semi-purified diet in which BSC1 added at the rate of 951 g/kg was the only source of N. Each treatment had 8 replicates and 6 birds per replicate. The experimental diets were fed for 5 D, birds were euthanized on day 28, and digesta from the terminal ileum were collected for chemical analysis (DM, titanium dioxide, N, and AA). The ingredient and chemical composition of the diets are shown in Table 2.

Expt. 3

A total of 72 Ross 308 male broiler chickens were used for the experiment and received the same pre-experimental and experimental diets similar to Expt. 1. The only difference was that BSC2 was used for this experiment. The ingredient and chemical composition of the diets are shown in Table 2.

Table 3. Ingredient and chemical composition (g/kg) of the experimental diets (Expt. 5).

Items	Control diet	Faba beans	Bean + barley mix	Lupin
Wheat	365.0	246.0	241.0	320.0
Corn	190	190	190	190
Soybean meal	345	265	280	240
Soybean oil	45.0	45.0	45.0	45.0
Monocalcium phosphate	15.0	14.0	14.0	15.0
Limestone	16.0	16.0	16.0	16.0
Titanium dioxide	5.0	5.0	5.0	5.0
Vitamin-mineral premix	5.0	5.0	5.0	5.0
DL-Methionine	4.0	4.0	4.0	4.0
L-Lysine·HCl	5.0	5.0	5.0	5.0
$NaHCO_3$	3.0	3.0	3.0	3.0
NaCl	2.0	2.0	2.0	2.0
Test feedstuff		200.0	190.0	150.0
Total	1,000	1,000	1,000	1,000
Analyzed nutrients and energy				
Protein	226.9	230.0	229.9	223.4
ME, kcal/kg	2,983	2,932	2,929	2,901
Ca	10.0	9.8	9.9	10.0
P	7.0	6.9	6.9	6.9
Available P	4.5	4.5	4.5	4.5
Na	1.7	1.7	1.7	1.7
K	9.4	7.2	7.5	7.0
Cl	2.0	1.8	1.8	1.8
Analyzed total amino acids, g/kg				
Arg	14.2	14.9	14.6	15.5
His	5.6	5.4	5.4	5.3
Ile	9.4	9.1	9.2	8.9
Leu	16.4	16.1	16.1	15.6
Lys	14.7	15.7	15.7	14.2
Met	6.3	6.7	6.5	6.0
Cys	3.4	3.2	3.2	3.3
Phe	10.4	9.9	9.9	9.5
Tyr	5.8	6.0	5.6	5.4
Thr	7.8	7.7	7.8	7.3
Val	10.1	9.9	9.9	9.5
Met + Cys	9.7	9.9	9.7	9.3
Phe + Tyr	16.2	15.9	15.5	14.9

Expt. 4

A total of 288 Ross 308 male broiler chickens were used for the experiment. The birds were raised together and received nutrient-adequate diets for the first 24 D post-hatch. On day 24, the chickens were weighed and allocated to 6 treatments in a randomized complete block design. The diets were an N-free purified diet and 5 semi-purified diets in which the test feedstuffs were added as the only source of N. Each treatment had 6 replicates and 8 birds per replicate. The experimental diets were fed for 5 D. The chickens were euthanized on day 28, and digesta from the terminal ileum were collected for chemical analysis (DM, titanium dioxide, N, and AA). The ingredient and chemical composition of the diets are shown in Table 2.

Expt. 5

A total of 240 Ross 308 male broiler chickens were used for a 21-D growth performance experiment. The birds were allocated at day zero to 4 treatments in a randomized complete block design. Each of the treatments had 6 replicates with 10 birds per replicate. The treatments included a wheat-SBM control diet and 3 additional diets in which faba beans or lupin partly replaced wheat and SBM. All the diets, formulated on digestible AA basis, were isoenergetic and isonitrogenous and met the breeder nutrient recommendation for Ross 308 male broilers (Aviagen, 2014). The ingredient and chemical compositions of the diets are shown in Table 3. The diets were fed as mash throughout the experiment. Birds and feed were weighed on days 0 and 21, and digesta from the terminal ileum were collected on day 21 by gently flushing the ileum with distilled water.

Chemical Analysis

Feedstuffs, diets, ileal digesta, and excreta were analyzed, as appropriate, for DM, N, titanium dioxide, GE, starch, and AA. Ti was analyzed using the method of Short et al. (1996). DM was determined by drying the samples in a drying oven (Uniterm, Russell-Lindsey Engineering Ltd., Birmingham, UK) at 105°C for 24 h (AOAC Method 934.01; AOAC, 2006). Total N content was determined by the combustion method (Method 968.06; AOAC, 2006). Gross energy was determined in an isoperibol bomb calorimeter (Model 6200, Parr Instruments, Moline, IL) using benzoic acid as an internal

Table 4. Ileal endogenous flow of amino acids in Expt. 2 and 4.

	Endogenous flow, g/kg dry matter intake	
	Expt. 2	Expt. 4
Ala	0.79	0.44
Arg	0.86	0.45
His	0.40	0.21
Ile	0.72	0.41
Leu	1.27	0.62
Lys	0.74	0.46
Met	0.20	0.17
Phe	0.65	0.43
Thr	0.81	0.67
Val	0.95	0.57
Asp	1.42	0.90
Cys	0.30	0.27
Glu	2.23	1.08
Gly	0.73	0.49
Pro	0.88	0.52
Ser	0.76	0.65
Tyr	0.59	0.29

standard. Samples for AA analysis were hydrolyzed for 24 h in 6 N hydrochloric acid at 110°C under an atmosphere of N. For Met and Cys, performic acid oxidation was carried out before acid hydrolysis. The AA in the hydrolyzate were determined by HPLC after post-column derivatization [AOAC, 2006, Method 982.30E (a, b, c)].

Calculations and Statistical Analysis

Apparent digestibility was calculated using the index method as previously described (Olukosi et al., 2007). The AME for BSC in Expt. 1 and 3 was calculated using the regression method as previously described (Adebiyi and Olukosi, 2015b). SIAAD (Expt. 2) was calculated as described by Adebiyi and Olukosi (2015a). The AME values of BSC1 and BSC2 (Expt. 1 and 3) were compared using paired *t*-test with the TTEST procedure of SAS. The data for Expt. 4 and 5 were analyzed using the MIXED procedure of SAS with blocks as random variable and the diet as fixed factor. Significantly different means were separated using the Tukey test. Significance was set at $P \leq 0.05$.

RESULTS

The analyzed composition of the feedstuffs shows that BSC2 had lower starch and higher N and GE levels compared with BSC1. The conventional faba bean (Expt. 4) had slightly higher contents of N and AA (except for Thr, Pro, and Tyr) compared with the organic faba bean. The endogenous ileal AA flow, generally lower for Expt. 4 birds, are presented in Table 4.

The AME for BSC2 was greater ($P < 0.05$) than that of BSC1 (Table 5). With the exception of Met, Thr, and Cys, the SIAADs were all greater than 80% (Table 5). Methionine had the lowest SIAAD of approximately 70%.

Table 5. Apparent metabolizable energy and nitrogen and standardized ileal amino acid digestibility (%) of bean starch concentrate (Expt. 1, 2, and 3).

	BSC1[1]	BSC2[1]	Pooled SEM	*P* value
AME, kcal/kg DM	3,298	3,446	11.0	<0.001
Nitrogen	85.2			
Indispensable amino acids				
Arg	90.9			
His	85.7			
Ile	83.5			
Leu	85.0			
Lys	87.7			
Met	69.9			
Phe	84.2			
Thr	77.7			
Val	85.3			
Dispensable amino acids				
Ala	84.0			
Asp	87.4			
Cys	78.9			
Glu	89.7			
Gly	82.1			
Pro	80.5			
Ser	81.6			
Tyr	82.9			

[1]BSC—bean starch concentrate—was obtained from air fractionation of ground, debranned faba beans. BSC1 (used in Expt. 1 and 2) was in pellet form whereas BSC2 (used in Expt. 3) was in powder form (not pelleted) and only used for metabolizable energy assay.

n = 8 replicate cages with 3 birds per replicate for metabolizable energy assay experiments, whereas n = 8 replicate cages with 6 birds per replicate for standardized ileal amino acid digestibility experiment.

SEM is standard error of the mean.

There was no difference in SIAAD of Arg, Phe, Asp, and Gly among corn, SBM, organic and conventional faba beans, and quinoa (Table 6). Generally, SIAAD was marginally greater in conventional, compared with organic faba bean, although not significantly different. In addition, SIAAD was not different between the faba bean and SBM, except for Met and Cys, and consequently total sulfur AA digestibility, which was greater ($P < 0.05$) for SBM compared with organic faba bean. The SIAADs of Met, Thr, Ser, and Tyr were lower ($P < 0.05$) for quinoa compared with SBM or corn but SIAAD of Thr was not different for quinoa and corn. The SIAADs of the other AA were not different among quinoa, corn, and SBM. The SIAAD for Ser was greater ($P < 0.05$) for conventional, but not organic, faba beans compared with quinoa. On the other hand, the SIAAD for Met was lower ($P < 0.01$) for both conventional and organic faba beans compared with the other feedstuffs.

The data of growth performance response of broilers to part replacement of SBM and wheat with faba beans or lupin are presented in Table 7. There were no treatment effects on any of the responses except FCR, which was greater ($P < 0.05$) for broiler chickens receiving faba bean + barley mix, or lupin, compared with the wheat-SBM control diet.

Part replacement of wheat and SBM with the different legumes tested had no effects on diet DM digestibility (Table 8), but ileal digestible energy tended to be greater for the lupin diet than for the control

Table 6. Standardized ileal amino acid digestibility (%) of the test legumes, soybean meal, and corn (Expt. 4).

	Corn	Soybean meal	Organic faba bean	Conventional faba bean	Quinoa	Pooled SEM	*P*-values
Indispensable amino acids							
Arg	85.0	85.4	82.8	84.6	80.4	0.19	0.306
His	86.6[a]	82.4[a,b]	74.7[b]	78.8[a,b]	78.0[a,b]	0.22	0.011
Ile	80.4	77.4	70.9	72.2	68.6	0.30	0.077
Leu	88.7[a]	77.8[a,b]	73.4[b]	75.2[b]	68.9[b]	0.29	0.002
Lys	68.6[b]	82.6[a]	80.1[a,b]	80.7[a]	74.4[a,b]	0.28	0.012
Met	86.9[a]	78.7[a]	59.8[b]	64.9[b]	78.3[a]	0.29	<0.001
Phe	82.5	78.4	71.4	74.2	70.0	0.32	0.070
Thr	67.1[a,b]	70.8[a]	67.6[a,b]	68.6[a,b]	54.0[b]	0.37	0.034
Val	87.2[a]	75.1[a,b]	69.4[b]	69.8[b]	63.9[b]	0.31	<0.001
Dispensable amino acids							
Ala	87.8[a]	75.2[a,b]	73.9[b]	71.0[b]	67.1[b]	0.31	0.002
Asp	76.9	77.5	75.7	78.3	66.7	0.31	0.092
Cys	84.8[a]	55.7[b]	31.0[c]	44.7[b,c]	55.9[b]	0.50	<0.001
Glu	88.1[a]	82.2[a,b]	81.5[a,b]	81.9[a,b]	75.3[b]	0.25	0.042
Gly	75.7	74.0	66.7	66.3	67.0	0.29	0.084
Pro	85.9[a]	75.3[a,b]	72.8[a,b]	66.8[b]	61.0[b]	0.35	0.001
Ser	78.9[a]	74.9[a]	69.8[a,b]	73.6[a]	59.0[b]	0.31	0.003
Tyr	71.6[a]	79.9[a]	67.3[a]	71.4[a]	47.5[b]	0.43	0.001
Met + Cys	85.8[a]	67.2[b]	42.3[c]	52.7[b,c]	67.9[b]	0.38	<0.001

[a,b]Means in the same row with different superscripts are significantly different ($P < 0.05$).
n = 6 replicate cages with 8 birds per replicate cage.
SEM is standard error of the mean.

Table 7. Growth performance of male broilers receiving diets in which different legumes partly replaced soybean meal (Expt. 5).

Items	IBW, g	FBW, g	BWG, g	FI, g/bird	FCR	Mortality, %
Control	38.4	884.2	845.8	1167.0	1.38[b]	0.00
Faba beans	38.1	845.0	806.9	1192.0	1.48[a,b]	1.67
Faba beans + barley mix	38.2	844.6	806.4	1233.1	1.54[a]	1.67
Lupins	38.6	811.8	773.2	1168.7	1.52[a]	0.00
Pooled SEM	0.359	19.6	19.5	26.9	0.024	1.217
P value	0.802	0.120	0.118	0.306	0.002	0.610

[a,b]Means in the same column with different superscripts are significantly different ($P < 0.05$).
IBW, initial body weight; BWG, body weight gain; FI, feed intake; FBW, final body weight.
n = 6 replicate pens with 10 birds per replicate pen.
SEM is standard error of the mean.

($P < 0.10$). Apparent AA digestibility was greater ($P < 0.01$) for the lupin-containing diet compared with the other diets except for Lys, Met, Thr, Ala, Asp, and Ser in Faba bean diet and Try in the control diet. On the other hand, AA digestibility in diet containing faba bean + barley mix was lower ($P < 0.05$) than for all the other diets, except for Arg, Asp, Ile, Lys, and Thr in which digestibility was comparable to the wheat-SBM control diet. Apparent AA digestibility was greater ($P < 0.05$) in faba bean diet compared with faba bean + barley mix diet. In addition, the faba bean diet had greater ($P < 0.05$) digestibility of Ala, Ile, and Lys but lower Pro digestibility compared with the wheat-SBM control diet. The digestibility of the other AA was similar between wheat-SBM control and faba bean diets.

DISCUSSION

The objective of the experiments reported here was to investigate the nutritive value of various legumes or their co-products for broiler chickens. The dependence on SBM as the main plant protein feedstuff for poultry raises several sustainability issues, and this is especially the case in Europe that depends largely on imported SBM (de Viser et al., 2014). Consequently, there is the quest for understanding the nutritive value of other feedstuffs that can be used to reduce reliance on SBM. All the legumes and co-products used in the experiment were grown in the United Kingdom and were unprocessed apart from drying and milling.

Chemical Profile of the Test Feedstuffs

The conventional faba bean used in Expt. 3 had marginally greater AA content compared with the organic faba bean. This may reflect the different agronomic practices involved in the cultivation of the beans as had been previously observed for wheat (Campiglia et al., 2015). On the other hand, the marginally lower N content of faba beans from intercropping field was largely an indication of contamination of faba beans with barley, driving down the overall protein

Table 8. Apparent ileal digestibility (%) of nutrients and amino acids for male broilers receiving diets in which different legumes partly replaced soybean meal (Expt. 5).

	Control diet	Faba beans	Bean + barley mix	Lupins	Pooled SEM	P value
DM	59.3	61.5	59.8	62.4	0.10	0.136
IDE, kcal/kg	2,820	2,964	2,916	3,035	4.78	0.055
N	78.3^{b}	77.7^{b}	74.2^{c}	82.6^{a}	0.06	<0.001
Indispensable amino acids						
Arg	85.6^{b,c}	87.0^{b}	84.2^{c}	89.8^{a}	0.05	<0.001
His	83.1^{b}	81.3^{b}	78.3^{c}	85.8^{a}	0.04	<0.001
Ile	81.0^{c}	81.2^{b}	78.1^{c}	84.9^{a}	0.05	<0.001
Leu	81.7^{b}	82.4^{b}	79.1^{c}	85.7^{a}	0.05	<0.001
Lys	86.5^{b}	88.3^{a}	85.5^{b}	89.6^{a}	0.04	<0.001
Met	91.5^{b}	92.2^{a,b}	89.8^{c}	93.6^{a}	0.04	<0.001
Phe	82.2^{b}	81.3^{b}	77.9^{c}	85.6^{a}	0.05	<0.001
Thr	70.6^{b,c}	72.3^{a,b}	67.4^{c}	75.8^{a}	0.10	<0.001
Val	79.9^{b}	80.6^{b}	76.7^{c}	83.9^{a}	0.05	<0.001
Dispensable amino acids						
Ala	78.6^{b}	80.8^{a}	76.7^{c}	82.9^{a}	0.05	<0.001
Asp	76.5^{b,c}	78.9^{a,b}	75.7^{c}	81.1^{a}	0.07	0.001
Cys	70.0^{b}	67.1^{b}	61.3^{c}	75.2^{a}	0.12	<0.001
Glu	86.3^{b}	85.3^{b}	83.1^{c}	89.2^{a}	0.04	<0.001
Gly	74.5^{b}	75.9^{b}	71.6^{c}	80.2^{a}	0.06	<0.001
Pro	84.3^{b}	79.6^{c}	76.7^{d}	87.2^{a}	0.05	<0.001
Ser	77.4^{b}	77.9^{a,b}	74.0^{c}	81.0^{a}	0.08	<0.001
Tyr	81.7^{a,b}	80.9^{b}	76.6^{c}	84.3^{a}	0.07	<0.001

$^{a\text{-}c}$Means in the same row with different superscripts are significantly different ($P < 0.05$).
n = 6 replicate pens with 10 birds per replicate pen.
IDE is ileal digestible energy.
SEM is standard error of the mean.

content of the faba beans. Intercropping of legumes with cereal grains is increasingly being practiced because it has many agronomic advantages, but challenges arise in keeping the cereal and legume grains separate especially for animal use (Tosti and Guiducci, 2010). Generally, N and AA profiles of the faba beans were similar to that reported by Woyengo and Nyachoti (2012).

Bean starch concentrates used in the current study were derived from air classification of faba beans. That processing technique separates the protein and starch components of legumes seeds (Vose et al., 1976). The relative composition of the starch and protein in BSC will depend on how much protein has been removed for other uses (for example, salmon feed in the current study). The CP level in the protein-rich fraction can be easily adjusted by altering the fineness of grinding and, or, speed and air flow rate (cut points) of the classifier (Van der Poel et al., 1990). Although the processing conditions used to produce BSC1 and BSC2 were not meant to be identical, the large difference in N and starch contents of the BSC1 and BSC2 batches used in the current studies demonstrates the variability in chemical composition that can easily result from alteration of steps in the air classification process. The protein content of the quinoa used in the current experiment was greater than was reported by others (Kozioł, 1992; Vega-Galvez et al., 2010). The high CP content of the sample used may have arisen from using a food grade quinoa in the current study.

Nutrient and Energy Utilization of the Feedstuffs

Metabolizable Energy of the BSC The AME of BSC1 was 3-percentage points lower than for BSC2. The 2 BSC were different both in chemical composition and physical characteristics. BSC1 had higher starch and lower N contents, but in addition was presented in pellet form, whereas BSC2 was presented in powder form. It is possible that the finer consistency of BSC2 contributed to greater energy availability due to its effect on reducing the content of native resistant starch (Colonna et al., 1980; Gunawardena et al., 2010b). Moreover, the pelleting process used for BSC1 may have reduced its AME level by negatively affecting starch digestibility (Svihus et al., 2004) with starch being the main energy source in the feedstuff.

Although BSC1 was mashed for physical consistency with the rest of the primary feedstuffs in the test diets (wheat and SBM), it was not ground to the consistency of BSC2. In addition, BSC2 had greater GE content (5%) than BSC1 and this may have contributed to its greater AME value. Notably, energy metabolizability values were 86 and 88% for BSC1 and BSC2, respectively, which can be considered marginally different, and possibly influenced by the presentation of the BSC to the chickens. The observation in the current study that BSC2 had greater AME, in spite of its lower starch content, supports the notion that AME of BSC is not primarily influenced by its starch content, as also previously observed for wheat (Wiseman et al., 2000).

The AME of the BSC in the current studies were greater than values reported for faba beans (Nalle et al., 2010; Hejdysz et al., 2016; Koivunen et al., 2016). The differences in AME content of faba beans have been related to their contents of starch, resistant starch, non-starch polysaccharides, phytate, vicine and convicine contents, raffinose, and galacto-oligosaccharides (Villarino et al., 2009; Nalle et al., 2010; Hejdysz et al., 2016). These components have different impacts on BSC digestibility because dehulling will have removed those components associated with the seed coat but, on the other hand, concentrated those associated with the endosperm. In addition, variation may arise from the thoroughness of dehulling, the proportion of starch to protein, processing of the fraction (e.g. pelleting) which may involve a measure of heat application, and variabilities in air classification processing (Van der Poel et al., 1990). The AME content of the BSC would make them marginally superior to whole faba beans as an energy source. However, maintaining a consistency in AME value of BSC will be a challenge because its chemical composition, and thus AME value, is easily influenced by changes in the parameters (e.g. speed) of air classification process.

Standardized AA Digestibility of BSC The SIAAD of BSC showed relatively high digestibility for most AA but poorer digestibility for the sulfur AA. Similar observation had been made previously for faba beans (Masey O'Neill et al., 2012; Koivunen et al., 2016). The implication of a combination of low content and relatively low digestibility value of sulfur AA is an overall low digestible sulfur AA content. Gunawardena et al. (2010a) reported modest levels of Met digestibility in BSC for pigs, but the level of standardized digestible Met in that study was poorest compared with other AA as also observed in the current study. This will put a limitation on inclusion level of the feedstuff that can be incorporated in replacement of SBM, without unduly increasing the amount of supplemental sulfur AA, especially Met. Nevertheless, a companion study with pigs demonstrated that this batch of BSC2 could replace SBM in growing pigs without negatively impacting their growth performance (Houdijk and Olukosi, 2014).

As was the case in the current study, the more economical part of air-fractionated pulses is the protein-rich component and therefore the efficiency of the process is measured as enrichment of protein content in the protein-rich component (Bergthaller et al., 2001). Consequently, the feasibility of using BSC in poultry and its availability to the feed industry will likely be dictated by the economics of using the protein-rich fraction in other sectors. However, because air fractionation enriches both the protein and starch fractions of pulses (by increasing protein contents of both fractions), the data from the current study show that BSC, if available, is a nutritive feedstuff for poultry especially if used in nutritionally balanced rations to ensure that the sulfur AA requirements of the birds are met.

Standardized AA Digestibility of Faba Beans and Quinoa Faba beans are widely cultivated in Europe, and with its AA profile, have the potential to be a widely accepted protein feedstuff. Faba beans produced in organic and conventional fields were assayed in Expt. 4. Both the content and the SIAAD for most of the AA were marginally greater for conventional faba beans compared with the organic faba beans. A combination of these factors indicates that the conventional faba bean had greater digestible AA content. However, SIAAD was typically similar between faba beans and SBM, especially for the faba bean from conventional system. Digestibility of the sulfur AA, and especially Cys, was very low for faba beans. This is similar to observation of low digestibility of sulfur AA for BSC in the current study as well as values reported by others (Nalle et al., 2010; Masey O'Neill et al., 2012; Woyengo and Nyachoti, 2012).

The AA digestibility values reported in the current study were similar to, or greater than, those reported by Masey O'Neill et al. (2012) for various UK-grown faba beans varieties. Others have reported similar, or higher, AA digestibility values for faba beans than reported in the current experiment (Nalle et al., 2010; Woyengo and Nyachoti, 2012). The AA digestibility values are apparently influenced by various factors including agronomic practices (as observed for faba bean from organic and conventional systems in the current report), the beans varieties (Masey O'Neill et al., 2012; Usayran et al., 2014; Koivunen et al., 2016), and associated with that, variation in their seed tannin content (Gatel, 1994; Woyengo and Nyachoti, 2012).

Quinoa is a pseudocereal that is primarily cultivated for human consumption. There are not many published data on the use of quinoa for broilers or on its nutritive value. In the current study, the AA digestibility of quinoa was generally lower than that of corn. Quinoa is known for its high-quality protein that is reported to be similar to that of casein (Repo-Carrasco et al., 2003). But in addition, it has functional food characteristics such as its antioxidant property (Vega-Gálvez et al., 2010) or saponin content of the hulls (Carlson et al., 2012). The latter, in addition to tannins and protease inhibitors, is an antinutritive factor commonly found in raw quinoa that may limit its inclusion in broiler diet (Gonzalez et al., 1989). Improta and Kellems (2001) observed that high dietary inclusion level of raw quinoa markedly reduced survivability of broiler chickens. But that was possibly due to excessive level of quinoa used in the study (> 900 g/kg) and the unmitigated low dietary crude protein level (130 g/kg) which led to poor feed intake. The authors also observed that washing, following polishing (removing the outer coat), was more effective than polishing alone for improving the growth performance of broilers receiving quinoa. In view of its protein quality and AA digestibility, use of quinoa in broiler diet will likely provide growth performance similar to that of wheat- or corn-SBM diet, provided that other antinutritional factors are not impeding e.g. feed intake.

Growth Performance and AA Utilization by Broilers Receiving Various Legumes The maximum inclusion levels used for the different legumes used in Expt. 5 were based on literature (Brenes et al., 1993; Nalle et al., 2010) and in an effort to maintain similar levels of CP and AME in all diets. The data showed that faba bean can provide growth performance and AA digestibility similar, or superior, to that obtained in wheat-SBM diet of similar nutritional profile. The reports from other studies in which faba beans partly replaced SBM similarly showed comparable performance between the birds receiving the control diet and those receiving faba beans (Nalle et al., 2010; Usayran et al., 2014). Gous (2011) observed that feeding graded levels of faba beans up to 250 g/kg did not depress broiler growth performance when broilers were fed pelleted diets. In addition, the data of Abdulla et al. (2016a,b) demonstrated the scope of increasing the dietary level of faba beans in the diet when supplemented with appropriate exogenous enzymes. It can be expected that the growth response to faba beans inclusion will depend on factors that influence its nutritive quality, compared to other protein feedstuffs such as their contents of non-starch polysaccharides, vicine and convicine, raffinose, and galacto-oligosaccharides (Villarino et al., 2009; Nalle et al., 2010; Hejdysz et al., 2016). Nonetheless, our observations suggest that partly replacing SBM with faba beans, on an equivalent digestible nutrient basis, will not have any deleterious effect on growth performance.

The chickens receiving the lupin-containing diet had FCR comparable to that of birds receiving faba beans-containing diets, but poorer FCR than that observed in the wheat-SBM control diet. Others have also reported reduced growth performance and feed intake in broilers fed lupins (Brenes et al., 2002; Rubio et al., 2003; Olkowski et al., 2005) but usually at dietary levels greater than used in the current study. Most often the poor weight gain was a result of depressed feed intake. In the current study, there was no significant difference in feed intake and weight gain among the treatments. Olkowski et al. (2001) reported dramatic reduction in performance and extensive toxicity issues with feeding raw or processed lupin in 21-day-old broilers but the authors used more than twice the level of lupins used in the current study. The antinutritive factors in lupins include alkaloids, raffinose-oligosaccharides, and α-galacto-oligosaccharides (Brenes et al., 1993). It has also been reported that with proper diet formulation it is possible to use up to 200 g/kg of lupins in broiler diets (Nalle et al., 2011). The negative effects of the NSP can be ameliorated, to some extent, with the use of exogenous enzymes (Brenes et al., 1993, 2002).

On the other hand, the lupin-containing diet had superior AA digestibility compared with the other diets. Rubio et al. (2003) reported no difference in AA digestibility of lupins- or wheat-SBM diets. Nalle et al., (2011) and Kazcmarek et al. (2014) observed relatively high AA digestibility for different varieties of lupins for broilers. The disparate effect of feeding lupins on growth performance and AA digestibility is puzzling. Further calculations showed that digestible AA intake (data not presented) was very similar in all the treatments, primarily driven by the superior AA digestibility in lupin-containing diet. On the other hand, the poor FCR in birds receiving the diet containing lupins in the current study was largely driven by low weight gain without any loss in feed intake. One possibility for the high AA digestibility is a physiological response driven by high antinutrient level in lupin-containing diet producing intestinal tissue hyperplasia (Olkowski et al., 2005) which may trigger an increase in AA digestibility. This intestinal hyperplasia would be expected to increase maintenance energy costs (Koong et al., 1982) and possibly lead to poorer weight gain in spite of greater digestible nutrient intake. On the other hand, the reversal of these effects with enzyme supplementation may help explain some of the positive effects observed when enzymes are supplemented in lupin-containing diets (Brenes et al., 2002; Rubio et al., 2003).

In conclusion, the observations from the current studies show that there is scope for using the assayed legumes, co-products, and quinoa in broiler chickens to partly replace SBM as protein feedstuff. Limitations to the quantity of these legumes that can be included in broiler diets will depend on the need to maintain optimum AA profile in the diet, avoiding reaching thresholds for antinutritional factors, as well as appropriate processing to facilitate inclusion of the feedstuffs with the others routinely used.

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